AD-A264 958

DTIC
ELECTE
MAY 20 1993
S C D

# NONLINEAR DYNAMICS IN OPTICAL SYSTEMS



93-05072

*Sponsored by*
Air Force Office of Scientific Research
Office of Naval Research

*For*
Optical Society of America

POSTDEADLINE PAPERS

JUNE 22–26, 1992
ALPBACH, AUSTRIA

93 3 9 031

# Tracking unstable phenomena in chaotic laser experiments: Extending the region of stability in a multimode laser

**Zelda Gills, Christina Iwata, and Rajarshi Roy, School of Physics, Georgia Institute of Technology, Atlanta, GA 30332, USA**
**Ira B. Schwartz and Ioana Triandaf, US Naval Research Laboratory, Special Project for Nonlinear Science, Code 4700.3, Washington, DC 20375-5000, USA**
**Telephone: 202 404 8359, Email: schwartz@nls4.nrl.navy.mil**

A new algorithm retains control of a chaotic laser over a large range of parameter values. Experiments show an order of magnitude increase in the region of stability in a multimode laser.

Presenter is Ira Schwartz

# Tracking unstable phenomena in chaotic laser experiments: Extending regions of stability in a multimode laser

**Zelda Gills, Christina Iwata, and Rajarshi Roy, School of Physics, Georgia Institute of Technology, Atlanta, GA 30332, USA**
**Ira B. Schwartz and Ioana Triandaf, US Naval Research Laboratory, Special Project for Nonlinear Science, Code 4700.3, Washington, DC 20375-5000, USA**
**Telephone: 202 404 8359, Email: schwartz@nls4.nrl.navy.mil**

Recently, experimental systems which exhibit chaos have been controlled using techniques such as OGY [1] and the related occasional proportional feedback, OPF [2]. The methods have been able to stabilize both low dimensional experiments, such as electronic circuits [2] as well as high dimensional multimode chaotic lasers [3]. Controlling a chaotic system consists of stabilizing an unstable steady state or periodic orbit by having the system perform small amplitude fluctuations about some fixed parameter value. The OPF method is implemented by choosing the fluctuations so that the system is brought closer to the unstable orbit of interest. In the OGY method, the fluctuations are chosen so that the iterates fall on the stable manifold of the unstable orbit, thus keeping the dynamics in the neighborhood of the point of interest in phase space. Both methods are clearly related [4].

One common drawback of the control method is its sensitivity to dc parameter changes. That is, if the dc value of the parameter is changed systematically, control is retained only in a small neighborhood of parameter space [5]. This is due to the fact that the point about which the system is controlled changes as a function of parameter. If the control point is not changed when the parameter changes, control is lost. However, in [5] it was shown how to move the control point so that the error between the control point and true fixed point is minimized. The basic idea was to observe that when the control point is exactly equal to the fixed point, the mean value of the control fluctuations is zero. If the control point is moved away from the true fixed point, the mean changes linearly. Therefore, if the dc parameter value is changed, then the control point is changed by minimizing the mean of the fluctuations. One is thus able to track the unstable orbits over large regions of parameter space. It is also possible to cancel the effects of parameter drift in experiments automatically using this technique.

A diode pumped solid state Nd:YAG (neodymium doped yttrium aluminum garnet) laser with an intracavity KTP (potassium titanyl phosphate) crystal displays chaotic fluctuations of the output intensity for certain operating parameter regimes [6]. An OPF technique for the dynamical control of the chaotic laser system was demonstrated recently. In this technique, the output is detected by a photodiode, the output from which is amplified with a variable gain and offset. The signal is then sampled periodically, at a period determined by an external synchronizing pulse generator. The sampled signal is input to the laser diode driver for a time short compared to the sampling period. For a description of the control technique, we refer the reader to [3]. There, we demonstrated that it is possible to stabilize a wide variety of periodic orbits of the chaotic laser system.

For a particular set of parameters, it was found that the laser operated in stable steady state very near threshold. As the pump power was increased, the laser displayed a sequence of periodic and chaotic behaviors. Fig. 1 shows the average value of the Nd:YAG laser output (relative units) at 1.06 $\mu$ as a function of the d.c. bias. The symbols used in the plot denote the steady state, periodic and chaotic behavior. Application of the OPF technique [3] allows us to stabilize the laser even when the steady state becomes unstable. Fig. 2a is an example of chaotic output from the laser without application of the control signal. Fig. 2b demonstrates the stabilization of the chaotic dynamics to a steady state when the control circuit is activated. The stabilized steady state intensity has the same average value as that of the chaotic output. The control signal fluctuations are extremely small and difficult to distinguish from noise in the digital oscilloscope traces.

Stabilizing and tracking the unstable steady state required that the control signal be adjusted for zero d.c. offset (from the preadjusted bias value of the diode laser driver), in accord with algorithms in reference [5]. Fluctuations in the pump power produced by the control circuit were also minimized by adjusting the time interval of application of the control signal and the frequency of sampling of the laser output. It was found that steady state could be maintained over a range of several kHz of the sampling frequency, which was nominally fixed at 80.7 kHz. In Fig. 3, we show the results of tracking the laser output in the steady state, using control optimization procedure described above. The laser displays periodic, chaotic, and steady state behavior when control is not applied over the same range of d.c. bias values (Fig. 1). The chaotic or periodic oscillations are typically a hundred times larger than the intensity fluctuations about the steady state observed with optimized control parameters, as is seen from Figs. 2(a) and (b).

We have further shown that when control is not optimized for each d.c. bias value, steady state behavior can only be maintained over a very small range of pump power (Fig. 4a). In these measurements, control was optimized at a d.c. bias of 272.9 mV to achieve steady state behavior. The average d.c. bias was then decreased, keeping all control parameters fixed. The laser almost immediately displayed periodic and chaotic pulsations. The corresponding control signal standard deviations are shown in Fig. 4(b). Control without tracking thus provides a stable steady state only over a very limited range of pump power.

A comparison of Figs. 1 and 3 immediately shows that the *tracking technique allows us to obtain about fifteen times more output power in a* <u>*stable steady state*</u> *for a given setting of the laser parameters.* The stabilized steady state values are very close to the average values for the fluctuating, unstable laser output for the same d.c. bias. Steady state operation achieved in this manner is extremely stable for long periods of time (many minutes).

Numerical computations are in progress to illustrate both control and tracking procedures. [7]

<u>Acknowledgments</u>: R.R. acknowledges support from NSF grant ECS 914232. Z.G. was supported by an AT&T graduate fellowship and C.I. by an NSF Research Experience for Undergraduates program. I.T. acknowledges support from the Office of Naval Technology. R.R. acknowledges an early remark by Jack Hale suggesting a continuation procedure of the type demonstrated here. He also acknowledges many helpful discussions with Pere Colet and Kurt Wiesenfeld.

References:

[1] Edward C. Ott, Celso Grebogi and James A. Yorke, Phys. Rev. Lett. 64,1196 (1990).
[2] E.R. Hunt. Phys. Rev. Lett 67, 1953 (1991).
[3] R. Roy, T.W. Murphy, T.D. Maier, and Z. Gills, PRL 68, 1259 (1992).
[4] B. Peng, V. Petrov, and K. Showalter, J. Phys. Chem. 95, 4957 (1991).
[5] I. B. Schwartz and I. Triandaf, "Tracking unstable orbits in experiments: A new continuation method", submitted to Phys. Rev. A.
[6] C. Bracikowski and Rajarshi Roy, Chaos 1, 49 (1991)
[7] P.Colet and Rajarshi Roy, "Control of chaos in a multimode solid state laser: Numerical results", TuA2 of the NDOS II meeting.

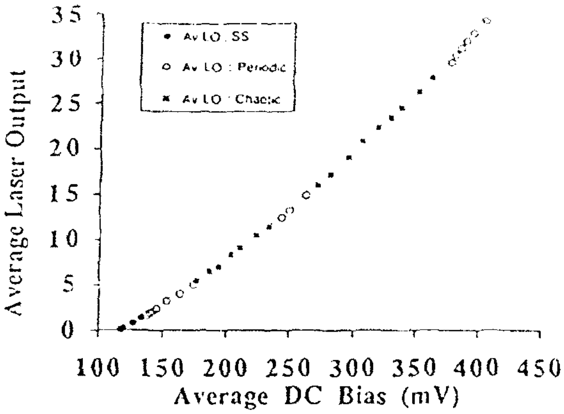


**Fig.1 Laser operation above threshold without control.**

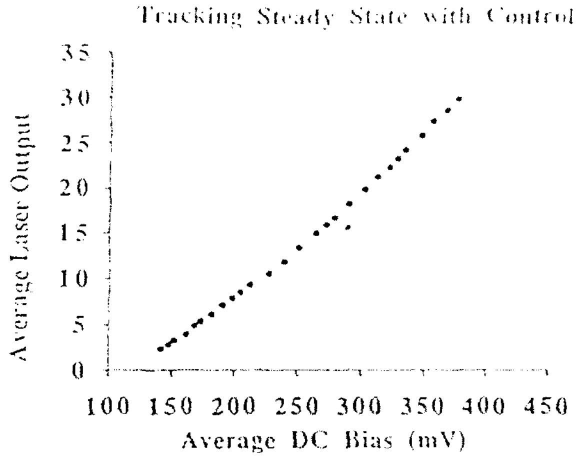


**Fig. 3**

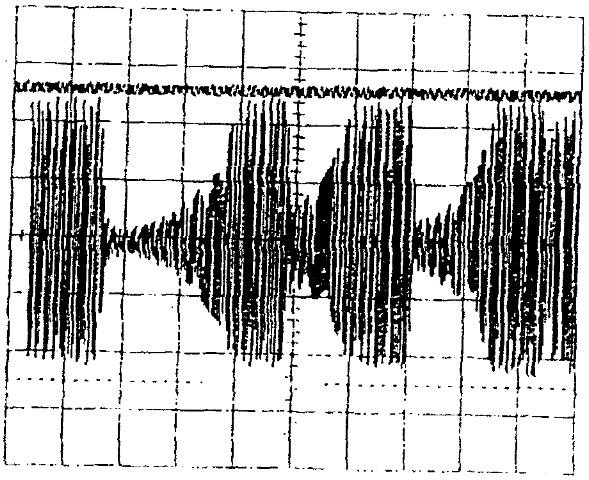

**Fig. 2a Chaotic laser fluctuations without control.**

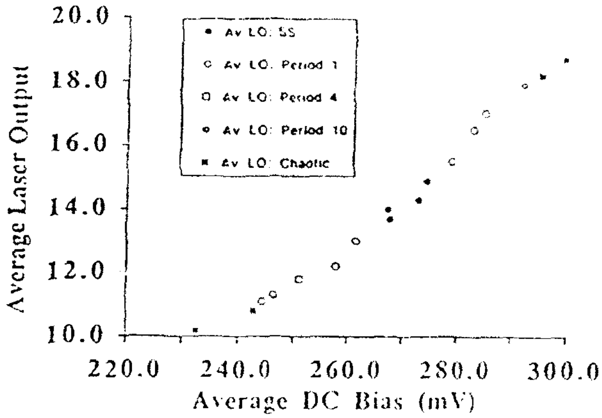


**Fig. 4a Control without tracking.**

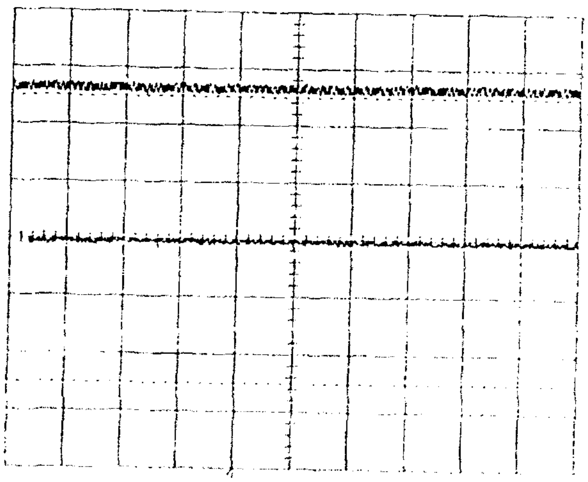

**Fig.2b Stabilized steady state with control.**

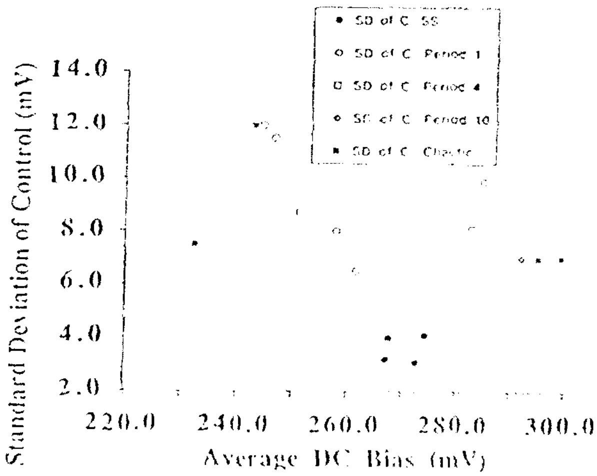


**Fig. 4b Control without tracking.**

# Two Dimensional Analysis on Nonlinear Interferometer and Decay of Spirals

H. Adachihara and H. Faid
Laboratoire Photophysique Moléculaire
Centre National de la Recherche Scientifique
Bâtiment 213, Université Paris-Sud 91405 Orsay, France

**Abstract**

Our two dimensional analysis on Vorontsov's nonlinear interferometer model reveals how to construct complex patterns with unstable eigenmodes and how spirals decay into petals.

Akhmanov, Vorontsov et al. have recently observed various, fascinating spatial patterns in their experiments with a nonlinear interferometer[1,2,3]. Their mathematical model is found to agree with experiments. Yet their one dimensional analysis treats only simple petal patterns and not more complex, truly two dimensional patterns. The model equation for the phase $U(x, y, t)$ of the beam is given by

$$\tau U_t + U = D\nabla^2 U + K_0(1 + \gamma \cos(\mathcal{R}U + \phi_0))$$

where $\tau(\approx 0.12 sec)$ is the relaxation time of the nonlinear response, $K_0$ the nonlinear (Kerr) strength, $\gamma$ the mirror loss, $\phi_0$ the phase shift in the cavity and $\mathcal{R}$ the rotation operator $\mathcal{R}U(r, \theta, t) = U(r, \theta + \Delta, t)$ in the polar coordinates. This equation is linearised around the *plane* fixed point $\bar{U}$ and its stability to a x-dependent perturbation is analysed using two dimensional Fourier cosine or sine modes.

Our two dimensional linear stability analysis gives stable/unstable spatial eigenmodes which correspond to stable/unstable manifolds. At the parameters $\Delta = 54°$, $D = 0.001$ and $K_0 = 2.2$, for example, the full model generates from a cosine perturbation a steady state of four rotating and ten stationary petals (Fig. 1). Our analysis predicts that at the same parameter values, one real and a pair of complex eigenvalues become unstable, which translates into a growth of ten stationary and four rotating petal eigenmodes (Fig. 2). At $K_0 \approx 2$ which seems typical in the experiments, our linear theory may be sufficient to determine overall patterns that finally emerge.

Rotating spirals which Vorontsov and et al have observed in the experiments may eventually unwind and reduce themselves into simpler petals due to the radial diffusion. With a strong diffusion, this unwinding process occurs quickly as seen in Fig. 3 where $D = 0.01$, about 20 times larger than the usual value. Under certain assumptions, the deformation of spirals may be expressed in the following diffusion equation for the phase shift $\phi(r, t)$ of the rotating spiral $f(\theta + \omega t - \phi(r, t))$

$$\phi_t = \frac{D}{\tau}\left(\phi_{rr} + \frac{1}{r}\phi_r\right) + C$$

where $C$ is some constant. With the parameter values of Fig. 3, $C$ turns out to be negative. Therefore, $\phi \to 0$ as $t \to +\infty$, i.e., spirals decay into petals with no $r$-dependent phase variation. With much less diffusion, the process may occur only slowly.

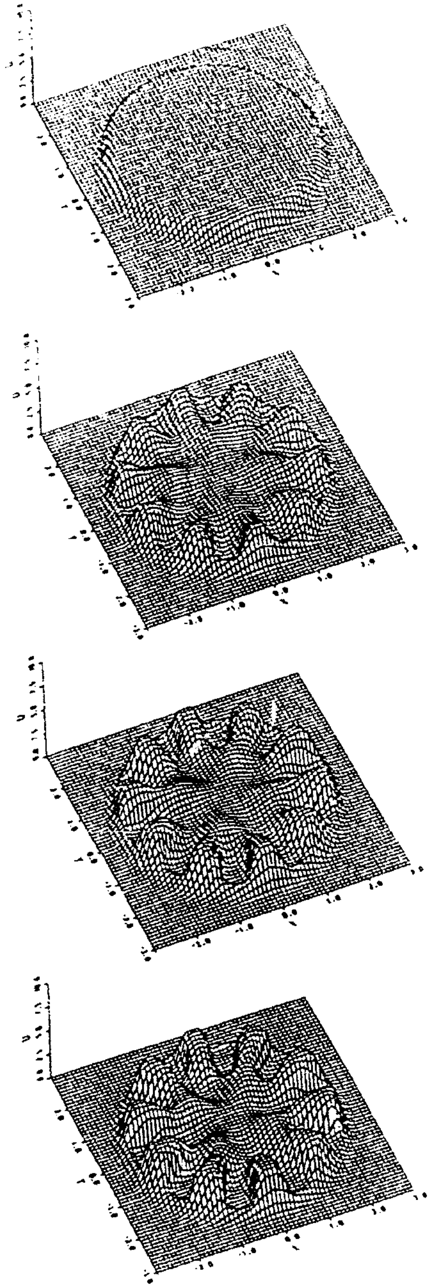

Fig. 1 A cosine perturbation evolves into a steady state of ten stationary and four rotating petals.

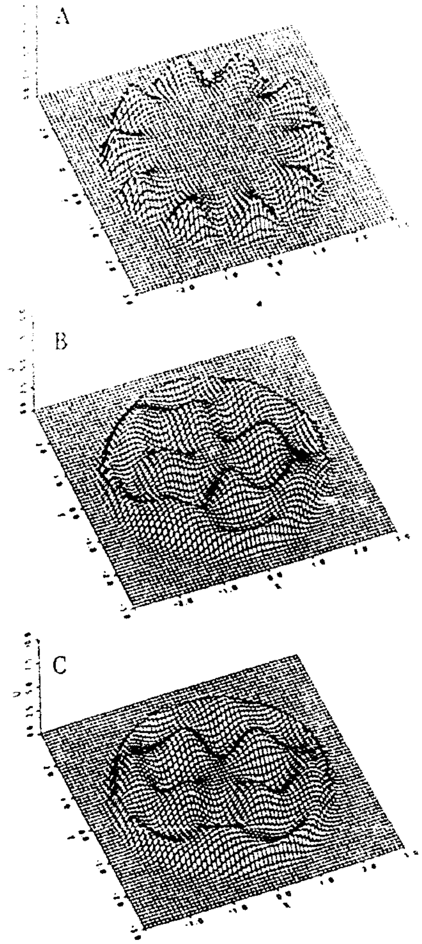


Fig. 2 Two dimensional analysis predicts two unstable eigenmodes: (A) ten stationary petals and (B,C) four rotating petals.

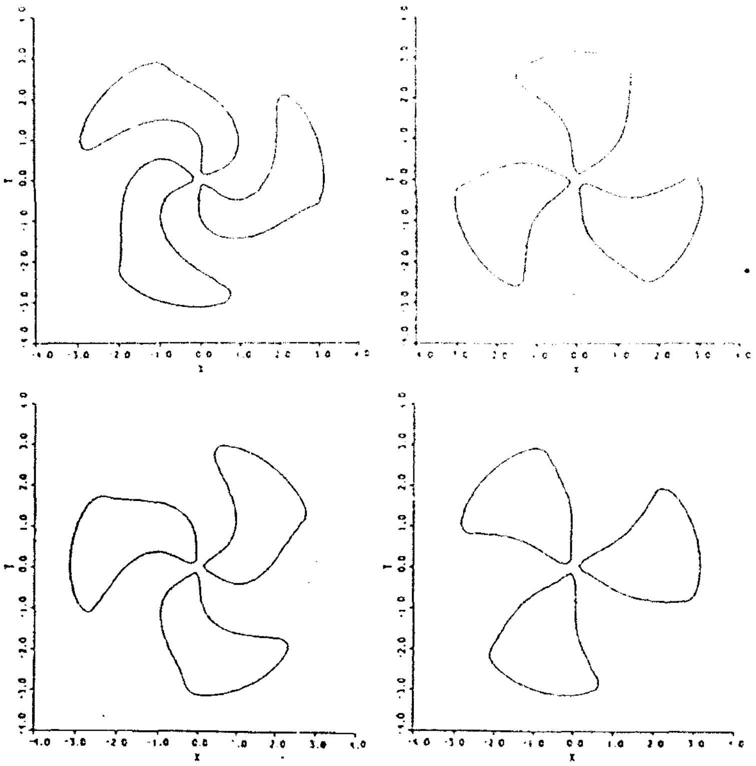

**Fig. 3** Diffusion in the radial direction eventually reduces spirals to petals. Here the level curve $U(r, \theta) = \bar{U}$ is plotted.

## References

[1]S. A. Akhmanov, M. A. Vorontsov and V. Yu. Ivanov, "Large-scale transverse nonlinear interactions in laser beams; new types of nonlinear waves; onset of optical turbulence", JETP Lett., Vol. 47, No. 12, 707-711 (1988).
[2]S. A. Akhmanov, M. A. Vorontsov, V. Yu. Ivanov, A. V. Larichev and N. I. Zheleznykh, "Controlling transverse-wave interactions in nonlinear optics: generation and interaction of spatiotemporal structures", J. Opt. Soc. Am. B **9**, 78-90 (1992).
[3]N. I. Zheleznykh, M. A. Vorontsov and A. V. Larichev, "2-D dynamics neural network optical system with simplest types of large-scale interactions", in *Nonlinear Optics in Diagnostics, Modeling and Control of Biological Objects and Processes*, S. A. Akhmanov and V. N. Zadkov eds., Proc. Soc. Photo-Opt. Instrum. Eng. **1402**, 154-164 (1990).

# Collapse of a Transverse Mode Continuum in a Photorefractive Oscillator

Mark Saffman, Don Montgomery, and Dana Z. Anderson

Department of Physics and Joint Institute for Laboratory Astrophysics
University of Colorado
Boulder, Colorado
80309-0440
telephone: 303-492-5202

## ABSTRACT

Collapse of a transverse mode continuum into a near-Gaussian single mode in an imaging photorefractive ring oscillator is predicted numerically and observed experimentally.

1?3-2

# Collapse of a Transverse Mode Continuum in a Photorefractive Oscillator

Mark Saffman, Don Montgomery, and Dana Z. Anderson

Department of Physics and Joint Institute for Laboratory Astrophysics
University of Colorado
Boulder, Colorado
80309-0440
telephone: 303-492-5202

The transverse field profile in oscillators with nonliinear media is determined by the interplay between the nonlinearity and the resonator geometry. In typical laser resonators the resulting field is a superposition of low order Hermite-Gaussian modes. However, there are some oscillator geometries, such as the self-imaging ring resonator[1],which do not lead to a well defined transverse mode. Since any optical ray is imaged back onto itself after one cavity round trip, there is no preferred optical axis. Diffraction effects will lead inevitably to high losses for rays which propagate far from the optical axis, however, there still exist a large number of possible modes, all with very similar losses. In this paper we show how to actively define the optical axis in such a self-imaging resonator by placing saturable photorefractive gain and loss nonlinearities in conjugate resonator planes. The transverse profile maximizes the oscillating power by saturating the photorefractive gain as little as possible, and saturating the photorefractive loss as much as possible. The resulting transverse mode turns out to be highly localized, but with an arbitrary axis of propagation inside the resonator.

The single transverse mode ring resonator with photorefractive gain and loss has been shown to exhibit bistability and self-pulsing[2]. The interesting dynamical behavior in this system is due to the competitive interaction of the gain and the loss. On the other hand, in the imaging resonator with a continuum of transverse modes, the interaction of the gain and the loss assumes a cooperative character in the following sense. Suppose the oscillation mode can be approximated by a Gaussian. Then its Fourier transform is also a Gaussian with a width inversely proportional to the input Gaussian. Place a photorefractive saturable gain nonlinearity, which tends to broaden a Gaussian field, in one plane, and the complementary photorefractive saturable loss nonlinearity, which tends to narrow a Gaussian field, in the conjugate plane. Thus both nonlinearities cooperate to encourage the formation of a narrow Gaussian in the plane of the loss medium. Combining this spatial dynamics with the bistability of the gain and loss configuration leads to the formation of a single well confined mode, and the suppression of all other transverse modes. Alternatively, the gain and loss interactions could be placed in image planes. In this case the interactions compete spatially. The gain tends to suppress any local intensity gradients, and the loss tends to amplify any intensity gradients. There is no localized solution that satisfies both nonlinearities and the result is a spatially periodic transverse pattern.

We have demonstrated transverse mode collapse in the self-imaging ring oscillator shown in Fig. 1. Energy is transferred to the resonator by two-beam coupling in photorefractive $BaTiO_3$ crystals. One of the crystals, located in the plane labelled $G$, is oriented to provide gain to the oscillating beam. The second crystal, located in the conjugate plane $L$, is oriented to provide loss to the oscillating beam. The gain pump is a $TEM_{00}$ Gaussian with spot size $w_c$, where $w_c = \sqrt{\lambda f/\pi}$ is the confocal mode size of

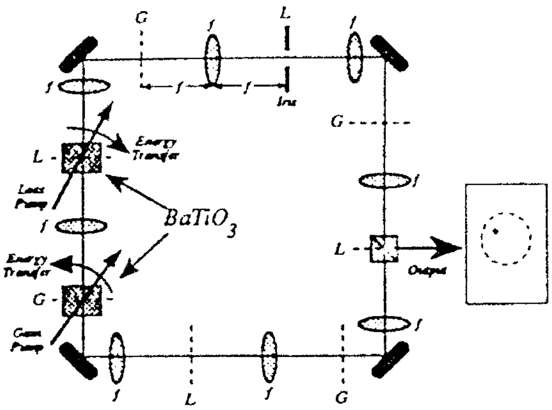


Fig. 1. Imaging ring resonator with photorefractive gain and loss. All lenses are f=100 mm with a spacing of 2f. The gain and loss pumps are from a cw Argon laser, $\lambda$=514 nm.

the equivalent linear resonator. The loss pump beam is an apertured plane wave with diameter of about 7 mm. The transverse extent of the oscillation is limited by a circular iris in plane $L$ with a diameter slightly less than 7 mm, which gives an equivalent Fresnel number in terms of the fundamental confocal mode, of about 750.

Consider first the situation when only the gain pump is turned on (Fig. 2, frame1). The position of the oscillating mode in plane $G$ is fixed by the pump beam, however its direction of propagation is undetermined since, for the chosen geometry, the photorefractive gain varies only slowly with small angular changes. In plane $L$ the oscillating mode fills the iris aperture with a speckle like structure. The oscillation constantly changes in a turbulent fashion, as has been studied in detail by Arecchi, et. al.[3]. If the round trip magnification differs from unity, or there is some offset or tilt in the cavity alignment then the oscillation does not fill the aperture uniformly, but instead assumes a transverse pattern indicative of the round trip equiphase contours. With careful alignment less than one fringe was visible across the transverse aperture.

The loss pump is then turned on. The gain and loss coupling coefficients and pump intensities would put the corresponding single-mode resonator in the bistable regime[2]. The oscillating field observed in plane $L$ collapses down to the single near-Gaussian mode shown in Fig. 2 frame 9. The mode size was measured to be roughly 2 $w_c$. The transverse position of the mode depends on the initial conditions, and can be seen at any transverse location. However, the mode is not spatially stable and moves about the aperture. A series of pictures would show the mode to traverse the aperture in the space of a few seconds. Interestingly, the mode does not wander randomly, but rather tends to repeatedly traverse a fixed trajectory. Typically the mode will appear on the side of the aperture where the gain is highest due to transverse pump depletion effects[4], and then move away along a direction determined by the cavity alignment. Depending on the details of the cavity alignment, and the gain and loss pump intensities, the spot either moves away to the edge of the aperture and disappears before reappearing again in its original position, or else it executes a cyclic motion wholly within the aperture. In the latter case the spot does not move in a closed circle but rather appears, moves a short distance, and then disappears, before repeating its motion.

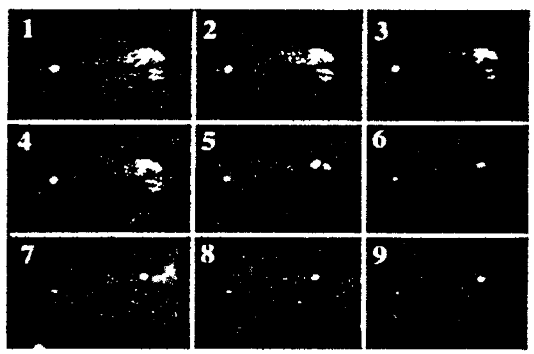


Fig. 2. Collapse of the transverse mode structure. Each frame shows an image of the gain plane on the left and the loss plane on the right. Each frame is separated by 1/30 sec.

We now turn to a model of the observed behavior. It is common, when analyzing the interaction of atomic or Kerr media with radiation fields, to eliminate the rapidly relaxing matter variables in favor of the slow field variables. When dealing with photorefractively pumped resonators the situation, however, is reversed. For typical experimental energy densities of 10 W/cm$^2$ the medium relaxation time in $BaTiO_3$ is of order 0.1 sec., whereas the field relaxes in order $10^{-8}$ sec. Therefore the appropriate description of the photorefractive resonator dynamics is in terms of the matter variables, i.e. the photoinduced gratings. In the limit of weak gratings the resulting equations can be approximated to yield a set of Lotka-Volterra type equations for the grating amplitudes. These equations describe the transient small signal behavior, but they are not valid in the strong signal regime where the photorefractive coupling is saturated.

To gain insight into the observed behavior without resorting to lengthy numerical calculations we have performed iterative calculations of the oscillating field in the nonphysical limit of medium relaxation time much shorter than field relaxation time. While the results so obtained s˙y nothing about the dynamic stability of the system, they do converge to self consistent solutions for the field profile, in the spirit of Fox and Li[5].

An example of the results is shown in Fig. 3. The calculation starts by assuming some initial distribution in plane $L$. In each iteration the field is Fourier transformed, propagated through the gain crystal, Fourier transformed again, propagated through the loss crystal, and multiplied by the passive cavity losses. The propagation in the photorefractive media is calculated by assuming thin crystals such that there is no direct coupling between different oscillating modes. The field rapidly converges to a near Gaussian distribution, which mimics the pump profile, and minimizes the gain saturation in plane $G$, and a localized spot which maximizes the loss saturation in plane $L$. The location of the steady state spot coincides with the peak of the assumed initial conditions.

These calculations also lend some insight into the transverse stability of the oscillating mode. The steady state spatial profiles of the gain and loss gratings are shown in Fig. 4, where the grating angle which determines the two-beam coupling rotation matrix[6] has been plotted as a function of the transverse coordinate. It can be seen that the loss grating has a local minimum. This serves to stabilize the transverse field profile, since fluctuations away from the center of the oscillating mode see increased loss. However, the stability of the gain and loss gratings themselves can not be determined from these calculations. In fact our experimental observations indicate that the oscillating mode stays localized while moving in the loss plane. This motion corresponds to a change in the phase shift across the gain grating and a simultaneous translation of the loss grating. Approaches to spatial stabilization of the oscillating mode, based on additional nonlinear interactions, are currently being investigated.

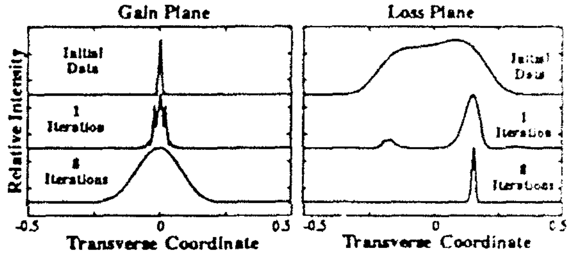


Fig. 3. Iterative calculation of the transverse intensity profile. The intensity has been normalized to the same maximum value at each iteration.

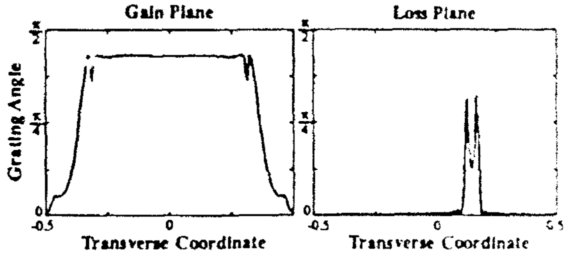


Fig. 4. Steady state grating angle profiles.

## References


1. J. A. Arnaud, Appl. Opt. **8**, 189-195 (1969).

2. D.M. Lininger, P.J. Martin, and D.Z. Anderson, Opt. Lett. **14**, 697-699 (1989); D.M. Lininger, D.D. Crouch, P.J. Martin, and D.Z. Anderson, Opt. Comm. **76**, 89-96 (1990).

3. F.T. Arecchi, G. Giacomelli, P.L. Ramazza, and S. Residori, Phys. Rev. Lett. **65**, 2531-2534 (1990).

4. A.A. Esayan, A.A. Zozulya, and V.T. Tikhonchuk, Sov. J. Qu. El. **21**, 1225-1230 (1991).

5. A.G. Fox and T. Li, Bell Sys. Tech. J. **40**, 453-488 (1961)

6. F. Davidson, L. Boutsikaris, and M. Krainak, Opt. Lett. **13**, 506-508 (1988).

Optical Society of America
Attendance Address Listing
Nonlinear Dynamics in Optical
As of February 10, 1993

Includes: ALL
Excludes: NONE

| Id# | Type | Last Name | First Name | Organization | Address (1) | Address (2) | Location |
|---|---|---|---|---|---|---|---|
| 014655 | | Abraham | Neal | Bryn Mawr College | Physical Sci. Bldg. | | Bryn Mawr, PA 19010, USA |
| 078158 | | Ackemann | Thorsten | Univ. of Muenster | | Correnstr. 2-4 | , Fed. Rep. Germany |
| 069372 | | Balle | S. | Univ. de les Illes Balears | | | Palma de Mallorca, Spain |
| 046023 | | Berry | M. | Univ. of Bristol Royal Fort | | Tyndall Ave. | Bristol, United Kingdom |
| 069326 | | Bielawski | S. | Univ. de Lille I | CNRS | BP 5 | Villeneuve d'Ascq, France |
| 028440 | | Blouin | Alain | Univ. Pierre et Marie Curie | de 1 Ecole Normale Superieure | 4 Place Jussieu Tour 12 E01 | Paris, France |
| 027358 | | Boggavarapu | Deepak | | | 2601 W. Kassandra Pl. | Tucson, AZ 85745, USA |
| 069227 | | Boixader | Francesc | Univ. Autonoma de Barcelona | | | Bellaterra, Spain |
| 079667 | | Bossert | David | Phillips Lab. | | Kirtland AFB | Albuquerque, NM 87117, USA |
| 055250 | | Brambilla | Massimo | Univ. of Milano | Sezione Di Elett. Non Lineare | Via Celoria 16 | Milano, Italy |
| 029601 | | Brivio | Franca | Italtel Sit | | | Settimo Milanese, Italy |
| 078656 | | Burak | Dariusz | Univ. of Kaiserslautern | | Erwin-Schrodinger Str. 46 | Kaiserslautern, Fed. Rep. Germany |
| 069163 | | Carr | Thomas | Northwestern Univ. | McCormick Sch of Eng/App Sci | | Evanston, IL 60208, USA |
| 069181 | | Castelli | Fabrizio | Univ. of Milano | | Via Celoria 16 | Milano, Italy |
| 033897 | | Cormier | Jean-Francois | Univ. Laval | | Pavillon Vachon | St. Foy, Canada |
| 050762 | | Danckaert | Jan | Vrije Univ. Brussel | | Pleinlaan 2 | Brussels, Belgium |
| 070883 | | Davis | Peter | ATR Opt. & Rad. Comm. Res. Lab | Sanpeidani, Inuidani | Seika-cho Soraku-gun, | Kyoto, Japan |
| 077783 | | De Lamare | Jacques | COGEMA-CEA | Lab. de Propagation | | Gif Sur Yvette, France |
| 022113 | | Depatie | David | US Air Force | PL/LIDA | | Kirtland AFB, NM 87117, USA |
| 029397 | | Dienes | Andrew | Univ. of California Davis | Bainer Hall Rm. 3110 | | Davis, CA 95616, USA |
| 069161 | | Erneux | Thomas | Northwestern Univ. | McCormick Sch. of Eng.& App.Sc | | Evanston, IL 60208, USA |
| 029374 | | Etrich | Christoph | Univ. Libre de Bruxelles | | Campus Plaine CP 231 | Brussels, Belgium |
| 069225 | | Farjas | Jordi | Univ. Autonoma de Barcelona | | | Bellaterra, Spain |
| 028297 | | Fermann | Martin Emanuel | Bellcore | | 331 Newman Springs Rd. | Red Bank, NJ 07701, USA |
| 024898 | | Firth | William | Strathclyde Univ. | John Anderson Bldg. | 107 Rottenrow | Glasgow, United Kingdom |

Includes: ALL
Excludes: NONE

| Id# | Type | Last Name | First Name | Orgcnization | Address (1) | Address (2) | Location |
|---|---|---|---|---|---|---|---|
| 069361 | | Fischer | Ingo | Philipps Univ. | Fachbereich Physik | Renthof 5 | Marburg, Fed. Rep. Germany |
| 005406 | | Fork | Richard | Rensselaer Polytechnic Inst. | | | Troy, NY 12180, USA |
| 035541 | | Francois | Pierre-Luc | Ctr. Natl. D'Etudes Telecom. | | Rte. de Tregastel | Lannion, France |
| 035764 | | Gao | Jin Yue | Jilin Univ. | | 79 Jie Fang Rd. | Changchun, China |
| 083203 | | Garus | Dieter | Lehrstuhl fur Allgemeine | Ruhr-Univ. Bochum | Universitatsstr. 150 | Bochum, Fed. Rep. Germany |
| 075305 | | Gavrielides | A. | US Air Force | PL/NOCT | | Kirtland AFB, NM 87117, USA |
| 047688 | | Geddes | John Bruce | Univ. of Arizona | Mathematics Dept. | | Tucson, AZ 85721, USA |
| 069119 | | Georgiou | Miltiades | Univ. Libre de Bruxelles | | Campus Plaine CP 231 | Brussels, Belgium |
| 036149 | | Glorieux | Pierre | Univ. de Lille 1 | | B.P. 5 | Villeneuve, France |
| 068305 | | Grebogi | Celso | Univ. of Maryland | | | College Park, MD 20742, USA |
| 069250 | | Harkness | Graeme | Univ. of Strathclyde | John Anderson Bldg. | 107 Rottenrow | Glasgow, United Kingdom |
| 042704 | | Harrison | Robert | Heriot-Watt Univ. | | Currie | Edinburgh, United Kingdom |
| 027786 | | Heatley | David Roy | Univ. of Strathclyde | John Anderson Bldg. | 107 Rottenrow | Glasgow, United Kingdom |
| 053730 | | Hennequin | Daniel | Univ. de Lille I | USTLFA associe au CNRS | BP 5 | Villeneuve d'Ascq, France |
| 069310 | | Hereth | R. | Ruhr-Univ. Bochum | | PO Box 102148 | Bochum, Fed. Rep. Germany |
| 069231 | | Herrero | Ramon | Univ. Autonoma de Barcelona | | | Bellaterra, Spain |
| 019547 | | Hilborn | Robert | Amherst College | | | Amherst, MA 01002, USA |
| 020940 | | Hoffer | Lois | Univ. Muenster | Westfalische Wilhelms | Corrensstr. 2/4 | Muenster, Fed. Rep. Germany |
| 069197 | | Hong | Feng-Lei | RIKEN | | Hirosawa 2-1 Wako-shi | Saitama, Japan |
| 078617 | | Jin | Yu De | Heriot-Watt Univ. | | | Edinburgh, United Kingdom |
| 068303 | | Kaneko | Kunihiko | Univ. of Tokyo | | Bunkyo-ku | Tokyo, Japan |
| 019088 | | Kawaguchi | Hitoshi | Yamagata Univ. | | 4-3-16 Jonan | Yonezawa, Japan |
| 048157 | | Kent | Andrew | Univ. of Strathclyde | John Anderson Bldg. | 107 Rottenrow | Glasgow, United Kingdom |
| 028821 | | Khanin | Yakov | Academy of Sci. of the USSR | | 46 Uljanov St. | Nizhnii Novgord, Russian Federation |
| 076859 | | Klehr | A. | Inst. fur Nichtlin. Opt. & | | Rudower Chaussee 5 | Berlin, Fed. Rep. Germany |

Includes: ALL
Excludes: NONE

| Id# | Type | Last Name | First Name | Organization | Address (1) | Address (2) | Location |
|---|---|---|---|---|---|---|---|
| 078157 | | Knop | Werner | ETH Zurich | | Gloriastr. 35 | Zurich, Switzerland |
| 026671 | | Kobsa | Henry | Du Pont Co. | PO Box 80715 | | Wilmington, DE 19880, USA |
| 050626 | | Kocharovskaya | Olga | Byelorussian Acad. of Sci. | | Ul. Ulyanova 46 | Nizhnii Novgord, Belorus |
| 046971 | | Kovanis | Vassilios | US Air Force | | | Kirtland AFB, NM 87117, USA |
| 075303 | | Kovanis | Vassilios | US Air Force | Nonlinear Optics Tech. Ctr. | | Kirtland AFB, NM 87117, USA |
| 042331 | | Lange | Wulfhand | Univ. Muenster | | Corensstrasse 2-4 | Munster, Fed. Rep. Germany |
| 020206 | | Lenstra | Daan | Free Univ. | | De Boelelaan | Amsterdam, Netherlands |
| 078211 | | Lerners | Roland | Ctr. Natl. D'Etudes Telecom. | | Rte. de Tregastel | Lannion, France |
| 005220 | | Lippert | Ernst | | | Eichendorffstr. 4 | Sonthofen, Fed. Rep. Germany |
| 025143 | | Lippi | Gian Luca | Univ. Muenster | Westfalische Wilhelms | Corensstr. 2/4 | Muenster, Fed. Rep. Germany |
| 042934 | | Liu | Yun | Shizuoka Univ. | | Johoku 3-5-1 | Hamamatsu, Japan |
| 025528 | | Lottici | Pier Paolo | Univ. Degli Studi | Viale Delle Scienze | | Parma, Italy |
| 069978 | | Lu | Weiping | Heriot-Watt Univ. | Phys. Dept. | | Edinburgh, United Kingdom |
| 019723 | | Mandel | Paul | Univ. Libre de Bruxelles | Campus Plaine CP 231 | Blvd. du Triomphe | Brussels, Belgium |
| 046238 | | McCall | M. | Imperial College | Optics Section | | London, United Kingdom |
| 027348 | | McCord | Alan | Univ. of Otago | | PO Box 56 | Dunedin, New Zealand |
| 079918 | | McInerney | John | Natl. Univ. of Ireland | Univ. College | | Cork, Ireland |
| 042821 | | Melnikov | Leonid | Chernyshevsky State Univ. | | Astrakhanskaya 83 | Saratov, Russian Federation |
| 042877 | | Meucci | R | Instituto Nazionale di Ottica | Arcetri | Largo Enrico Fermi, 6 | Firenze, Italy |
| 069213 | | Meziane | B. | Ecole Nat. Super. des Sci. | | 6, rue de Kerampont | Lannion, France |
| 043090 | | Mitschke | Fedor | Univ. of Hannover | | Welfengarten 1 | Hannover, Fed. Rep. Germany |
| 078159 | | Moeller | Michael | Univ. of Muenster | | Corensstrasse 2-4 | , Fed. Rep. Germany |
| 047682 | | Moloney | Jerome | Univ. of Arizona | | | Tucson, AZ 85721, USA |
| 062725 | | Moskowitz | Donna | | | 12-10 400 McChesney Ave. Ext. | Troy, NY 12180, USA |
| 069378 | | Neubecker | R. | Inst. of Applied Physics | | Hochschulstr. 6 | Darmstadt, Fed. Rep. Germany |

Includes: ALL
Excludes: NONE

| Id# | Type | Last Name | First Name | Organization | Address (1) | Address (2) | Location |
|---|---|---|---|---|---|---|---|
| 015726 | | Newton | Steven | Hewlett-Packard | PO Box 10350 MS 26M10 | 3500 Deer Creek Rd. | Palo Alto, CA 94304, USA |
| 062750 | | Nichols | Doyle | Univ. of Michigan | | 1301 Beal Ave. | Ann Arbor, MI 48109, USA |
| 069332 | | Ning | C. | Univ. Stuttgart | | Pfaffenwaldring 57/4 | Stuttgart, Fed. Rep. Germany |
| 015917 | | Ohtsubo | Junji | Shizuoka Univ. | | 3-5-1 Johoku | Hamamatsu, Japan |
| 027721 | | Oraevsky | Anatoly | P. N. Lebede Phys. Inst. | | 53 Lenin Prospect | Moscow, Russian Federation |
| 029099 | | Otsuka | Kenju | NTT | Otsuka Res. Group | 3-9-11 Midori-cho Musashino | Tokyo, Japan |
| 069132 | | Pesquera | Luis | Univ. de Cantabria | Fisica Moderna Dept. | Avda de Los Castros SN | Santander, Spain |
| 043568 | | Peterson | Phillip | US Air Force | Quantum Optics Lab. | | Kirtland AFB, NM 87117, USA |
| 027968 | | Pettiaux | Nicolas P.F. | Univ. Libre de Bruxelles | CP 231 | Blvd. du Triomphe | Brussels, Belgium |
| 029677 | | Piche | Michel | Univ. Laval | | Pavillon Vachon | St. Foy, Canada |
| 069191 | | Prati | Franco | Univ. di Milano | | Via Celoria 16 | Milano, Italy |
| 068307 | | Rabinovich | Michail | Inst. of Apply. Phys. | Bldg. 46 | Ul'Anova | Novgorod, Russian Federation |
| 076807 | | Ramazza | P. | Inst. Nazionale Di Ottica | | Largo Enrico Fermi 6 | Firenze, Italy |
| 069115 | | Rivlin | Lev | Moscow Inst. of Radioeng. | | 78 Vernadsky Prospekt | Moscow, Russian Federation |
| 028291 | | Rodgers | Robert Aubrey | | | 216 Creek Trail | Madison, AL 35758, USA |
| 069292 | | Rosanov | N. | State Optical Inst. | | | St. Petersburg, Russian Federation |
| 016428 | | Roy | Rajarshi | Georgia Inst. of Tech. | | | Atlanta, GA 30332, USA |
| 069355 | | Sacher | Joachim | Philipps Univ. | Fachbereich Physik | Renthof 5 | Marburg, Fed. Rep. Germany |
| 029711 | | Saffman | Mark | Univ. of Colorado | | Campus Box 440 | Boulder, CO 80309, USA |
| 053162 | | Sanchez | F. | ENSSAT | BP 447 | 6 Rue de Kerampont | Lannion, France |
| 069974 | | Sauer | M. | Inst. of Applied Physics | | Hochschulstr. 6 | Darmstadt, Fed. Rep. Germany |
| 027946 | | Shore | Keith Alan | Bath Univ. | | Claverton Down | Bath, United Kingdom |
| 069518 | | Staliunas | K | Braunschweig PTB | | Bundesallee 100 | Braunschweig, Fed. Rep. Germany |
| 069199 | | Sugawara | Toshiki | Univ. of Tokyo | Fac. of Sci. | 7-3-1 Hongo Bunkyo-ku | Tokyo, Japan |
| 027560 | | Tachikawa | Maki | Univ. of Tokyo | | 7-3-1 Hongo Bunkyo-ku | Tokyo, Japan |

Optical Society of America
Attendance Address Listing
Nonlinear Dynamics in Optical
As of February 10, 1993



Includes: ALL
Excludes: NONE

| Id# | Type | Last Name | First Name | Organization | Address (1) | Address (2) | Location |
|---|---|---|---|---|---|---|---|
| 028905 | | Tallet | Andree | Univ. de Paris XI | Bat. 213 | 15 Rue G. Clemceau | Orsay, France |
| 078616 | | Tan | Weihan | Heriot-Watt Univ. | | | Edinburgh, United Kingdom |
| 069121 | | Tang | DingYuan | Phys. Tech. Bundesanstalt | Lab. 4.42 | | Braunschweig, Fed. Rep. Germany |
| 069203 | | Tanii | K. | Univ. of Tokyo | | 7-3-1 Hongo Bunkyo-ku | Tokyo, Japan |
| 069368 | | Torrent | M. | Univ. Politecnica de Catalunya | Fisica i Eng. Nuc. Dept. | Colum 1 | Catalunya, Spain |
| 043181 | | Trillo | Stefano | Fondazione Ugo Bordoni | | Via Baldassarre Castiglione 59 | Rome, Italy |
| 069984 | | Uppal | J. | Heriot-Watt Univ. | Phys. Dept. | | Edinburgh, United Kingdom |
| 069130 | | Valle | A. | Univ. de Cantabria | Fisica Moderna Dept. | Avda de Los Castros SN | Santander, Spain |
| 069296 | | Viktorov | E. | S.I. Vavilov State Opt. Inst. | | | St. Petersburg, Russian Federation |
| 028119 | | Vilaseca | Ramon | Univ. de Valencia | Dr. Moliner 50 | | Burjasot, Spain |
| 015218 | | Winful | Herbert | Univ. of Michigan | EE-CS Bldg. | | Ann Arbor, MI 48109, USA |
| 028803 | | Zel'dovich | Boris | Chelyabinsk Polytechnic Inst. | | Pr. Lenina 76 | Chelyabinsk, Russian Federation |